PREDICTED WATER IMMERSION SURVIVAL TIMES FOR ANTI-EXPOSURE ENSEMBLES

Barry S. Shender, Ph.D., and Wendy Todd
NAVAIR Human Systems Department, Patuxent River, MD

ABSTRACT

NAVAIR has developed several new concepts for aviator anti-exposure assemblies. Regional insulation levels (immersed clo) of several configurations (a COTS drysuit, the CWU-86/P drysuit, varying types of undergarments including the Multi-Climate Protection system, and a COTS shorty wet suit) were determined using the Navy Clothing and Textile Research Facility's thermal manikin. The manikin was immersed in 20ºC turbulent water and was positioned in either a USN or USAF floating posture. These data were used to predict core (rectal) and regional skin temperatures in water ranging from 35ºF to 68ºF using the Wissler model for three male cases: (1) 140lb. with 8mm mean skin-fold thickness (MST); (2) 170lb. with 10mm MST; (3) 205lb. with 12mm MST. During the first 30 min, high metabolic levels were used to model swimming followed by 330 min of resting metabolism to represent energy conserving behaviors. Model results were used to generate a table of estimated immersed survival times based on the predicted exhaustion of metabolic stores. The results demonstrated the relationship between the ability to survive and water temperatures, time immersed, level of insulation, and body type. These guidelines can be used by aircrew to choose anti-exposure clothing suitable for mission conditions.

INTRODUCTION

US Navy interest in garments providing integrated protection against chemical agents, hyperthermia, hypobaria, and hypothermia has led to fabrication of prototype multi-purpose garments. As part of the development process, these garments need to be tested for the protection they provide against these hazards. Mathematical modeling can be used to simulate the thermal protection provided by the various garment designs and minimize laboratory testing. It can also be used to establish guidelines on the amount of clothing insulation required to withstand exposures of various durations under conditions of thermal stress.

This paper reports on the theoretical evaluation of hypothermia protection provided by nine clothing configurations intended for cold over-water flights during simulated head-out cold water immersion (CWI) using the Texas Human Thermal Model[10] (THTM), as modified by NAVAIR for use with low CLO values[7]. THTM can aid in clothing design by allowing specification of insulation values for up to fifteen body segments. This is an improvement over earlier work, in which researchers based their conclusions on an overall mean clo value for garments[9]. This paper is the first of a two-part effort and reports on nine of seventeen configurations measured and modeled. Part 2 will report the immersed clo values and survival times for the remaining clothing configurations. Part 2 will also investigate whether flotation angle or restrictive flight gear items (torso harness, anti-G garment, and survival vest) have a practical effect on immersed clo values.

Currently, the only guidance provided to USN aircrew for surviving cold immersed mishaps is the OPNAV 3710.7T[12]. The instruction requires that anti-exposure suits (*i.e.* dry suits) be worn if the water temperature is less than 50°F. However, if the water temperature is between 50°F and 60°F, dry suit wear it is up to the judgment of the unit command based on Figure 1 and probable rescue times. Unfortunately, the command does not currently have objective detailed data upon which to determine what garments need to be worn and when. Therefore, the goal of this study was to develop a family of risk curves based on the level of garment insulation and anthropometrics to provide guidelines for safe immersed exposure times.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **OCT 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Predicted Water Immersion Survival Times for Anti-Exposure Ensembles**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NAVAIR Human Systems Department Patuxent River, MD**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Published in the Proceedings of the Forty Third Annual SAFE Association Symposium, Held in the Salt Lake City, Utah, October 24-26, 2005. SAFE Assocation, Post Office Box 130, Creswell, OR 97426-0130. http://www.safeassociation.org

14. ABSTRACT

15. SUBJECT TERMS
Safe

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

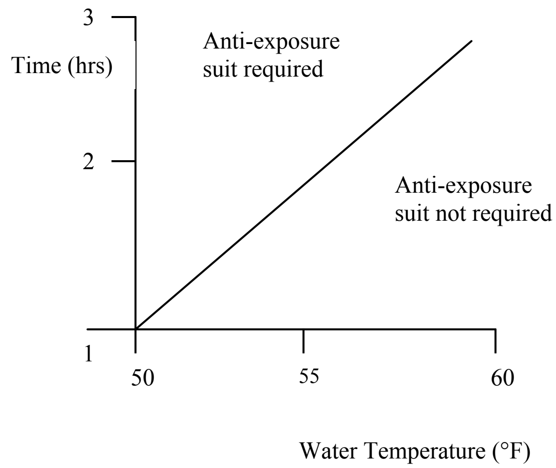

Figure 1. "Figure 8-2 Anti-Exposure Suit Requirements" reproduced from OPNAVINST 3710.7T[12].

METHODS

THTM provides predicted thermal response data for males only. The model can account for variations in weight, body fat (BF), and metabolic rate. For this study, three anthropometric cases were used: (1) 140 lb. and 16.8% BF (8 mm mean skinfold thickness (MST)); (2) 170 lb. and 19.2% BF (10 mm MST); and (3) 205 lb. and 21.2% BF (12 mm MST). The emergency scenario included high levels of activity to model swimming and boarding a raft during the first 30 min, followed by 330 min of inactivity to model resting in the raft conserving energy. Metabolic rates were calculated according to Brooks and Fahey[2] and are given in Table 1. The 360 min immersion scenario was determined for seven temperatures of calm water with 1 mph (30 knot) winds. (Note that it is not possible to include wave effects in the model; however immersed clo values were measured in continuous 1 to 1.5 foot waves.) Water temperatures were 35, 40, 45, 50, 55, 60, and 68ºF.

Estimates of rectal temperature (Tre) and central temperature (Tc) were generated as a function of immersion time. Tc was defined as the predicted temperature located in the head at the level of the hypothalamus. The maximum possible exposure duration for each garment in each environment was defined as either completion of the 6 hour immersion or the point at which the THTM predicted metabolic fatigue. This occurred when the energy derived from aerobic metabolism was exhausted with a concomitant buildup of lactic acid (the byproduct of anaerobic metabolism), at which point shivering ceased. THTM indicated that fatigue had been reached by a transient rise in Tc.

THTM separates the body into fifteen regions including head, chest, abdomen, right and left thighs, calves, feet, biceps, forearms and hands. A clo value can be specified for each area. Clo is a measure of intrinsic insulation (*i.e.*, without the adhering boundary still air layer) defined as follows[4]: 1 clo of insulation equals 0.18ºC*m^2*hr/kcal, or 5.55 kcal/m^2*hr*deg C. Immersed insulation values for nine different clothing configurations were obtained by the Naval Clothing and Textile Research Facility (NCTRF), Natick, MA from measurements using an immersed copper manikin and are given in Table 2. Three sets of clo values were supplied, labeled 120, 240 and 360 min. For modeling purposes, 120 min values were used during minutes 0-120, the 240 min values were used during minutes 121-240, and the 360 min values were used during minutes 241-360.

The clothing configurations used in this study comprise different combinations of dry suits, thermal liners, and undergarment layer(s) with the helmet, wool socks, and boots held constant (Table 3). Because the chief intent of this work was to provide decision making guidelines, typical clothing combinations by mission platform type were tested. Each clothing component is described below.

CLOTHING COMPONENTS

Dry Suits:

CWU-62B/P Series Anti-Exposure Coverall. This Navy dry suit is a one-piece coverall with permanently installed booties and wrist/neck seals. The body and booties are made of a water-impermeable PTFE-trilaminate fabric, heat-sealed to exclude water. The wrist and neck seals are made of latex rubber and are custom fitted to a watertight condition to each wearer.

CWU-86/P Anti-Exposure Coveralls. This Navy dry suit is essentially a ruggedized version of the CWU-62B/P, enabling the CWU-86/P to be worn without the flight coverall. In addition, the fabric used for the body has a durable water repellent finish. The wrist seals are neoprene rubber, and the neck seal is latex rubber, and each is custom fitted to a watertight condition to each wearer.

Multifabs Survival™ OTS-600 ("Over-The-Side"). This commercial dry suit is a one-piece coverall with permanently installed booties and wrist/neck seals. The body and booties are made of a water-impermeable PTFE-trilaminate fabric, heat-sealed to exclude water; however the inner surface is fleeced for extra insulation. The wrist seals are neoprene rubber, and the neck seal is latex rubber, and each is custom fitted to a watertight condition to each wearer.

Thermal Liners:

CWU-23/P Liner. This USAF liner is a one-piece coverall with long sleeves and long legs with a shorter-than-normal inseam to clear the tops of flight boots. The body is made of polypropylene netting backed with 100% cotton.

MCP (Multi-Climate Protection) Heavyweight Liner. This Navy liner comprises a long-sleeved top and pant made of black 200-weight aramid double velour. The zip-neck top has close fitting knit cuffs, a mock turtleneck collar, and an aramid mesh shirt-tail hem to reduce bulk. The liner pant has a front fly, an elastic waist, an aramid mesh crotch and inseam to reduce bulk, and elastic stirrups.

XCEL® Icon Shorty Wetsuit. This commercial wetsuit is not designed to be a thermal liner, but some Navy aircrews would like to wear it as one during conditions when a dry suit is too much, but a flight suit with thermal underwear is not enough. The "Icon" shorty wetsuit is a 1 mm thick neoprene with smooth finish inner surfaces and nylon tricot laminate outer surfaces. It has short sleeves and short legs.

Multifabs Survival™ Thermal Insulating Garment. This commercial liner is constructed of a polyester batting sandwiched within layers of woven polyester microfiber fabric. It has long sleeves, long legs, and rib knit cuffs at the neck, wrist, and ankles.

Thermal Underwear

CWU-43/P and CWU-44/P. This Navy undergarment set comprises a top and pant made of an aramid waffle-weave knit. The top has a turtleneck and long sleeves. The pant has long legs with close-fitting knit cuffs and elastic stirrups.

MCP Lightweight Underwear. This Navy undergarment set replaces the CWU-43/44s, and comprises a top and pant made of, aramid, raschel knit. The top has a crew neck, extended cuffs with thumbholes, and a shirt-tail hem. The pant has an elastic waist and stirrups.

MCP Mid-weight Underwear. This Navy undergarment set is constructed of an inner aramid fleece with a polyester-spandex face to provide a close fit. The top has a mock turtleneck in a close-fitting rib knit, and the shirt-tail hem is an aramid raschel knit to reduce bulk. The pant has stirrups, front fly, elastic waist, and raschel knit inseam gussets to reduce bulk.

Flight Gear:

Standard Wool Socks. These are made of 100% wool knit, and are knee high. Wool socks are worn over the booties of the anti-exposure suits used in this study.

CWU-27/P Flight Coverall. This quad-service garment is a long-sleeved coverall made of a 4.4 ounce plain weave aramid cloth. It has pockets on the chest, thighs, calves, and left arm. The wrists are wrap cuffs, and the ankles zip to allow a closer fit. This garment is worn on the outside of the OTS-600 and CWU-62 series dry suits. It is not considered to add immersed insulation because it wets through.

HGU-84/P or 68/P Helmet. These Navy helmets are each composed of a lightweight shell constructed of a multi-layer mixed composite of graphite fabric and ballistic nylon cloth, a polystyrene liner, and a 5-layer thermo-plastic inner liner that is dimpled to reduce bulk and allow airflow. A knit cloth cover encases the inner liner. The helmet acts to insulate the head from heat loss.

PCU-56/P Parachute Torso Harness. This Navy harness is an open structure that is fitted tightly to the torso. Thick nylon webbing passes around the shoulders, chest, seat, and legs, and a nylon cloth panel zips closed in the front.

CSU-13B/P Anti-G Suit. This USAF/Navy garment is a “chaps” wrap-around style with cutouts at the knees, groin, and seat. The garment comprises polyurethane-coated nylon bladders encased in aramid cloth pockets, the whole being secured to the body by zippers at the inside legs and side waist. The anti-G- suit is adjusted by lacings to a tight fit to the individual wearer.

CMU-33/P Survival Vest. This Navy garment is constructed of a flame resistant (FR) nylon mesh with FR nylon webbing pocket mounts and heavy aramid cloth pockets over the surface. It is fitted snugly but not tightly to the wearer.

Aircrew Safety Boots. These Navy flight boots are constructed of calfskin lined with full-grain, glove-leather uppers; cold-rolled carbon steel toe caps, padded toe boxes, removable cushioned insoles, and nitrile rubber outsoles.

Table 1. Metabolic rates for males modeled in this effort.

Male Weight (lb.)	Basal (W)	Exercise (W)	Resting (W)
140	97.6	237.1	122.0
170	118.6	292.9	146.4
205	139.5	348.7	174.3

Table 2. Total and regional immersed clo values.

Clothing Configuration	Time (min)	Total	Torso	Head	Legs	Feet	Arms	Hands
1	120	0.08	0.20	0.04	0.21	0.28	0.20	0.01
	240	0.07	0.17	0.03	0.17	0.24	0.18	0.01
	360	0.07	0.17	0.03	0.17	0.20	0.18	0.01
2	120	0.12	1.02	0.15	0.46	0.29	0.79	0.01
	240	0.10	0.42	0.06	0.35	0.28	0.41	0.01
	360	0.09	0.32	0.05	0.32	0.27	0.32	0.01
3	120	0.17	0.57	0.17	0.39	0.21	0.48	0.02
	240	0.17	0.56	0.19	0.31	0.20	0.45	0.02
	360	0.16	0.55	0.19	0.29	0.19	0.44	0.03
4a	120	0.15	0.73	0.68	0.44	0.26	0.30	0.02
	240	0.14	0.73	0.65	0.36	0.24	0.20	0.02
	360	0.13	0.71	0.65	0.34	0.20	0.16	0.02
4b	120	0.13	0.31	0.72	0.20	0.30	0.27	0.02
	240	0.12	0.29	0.67	0.18	0.29	0.24	0.02
	360	0.12	0.28	0.67	0.17	0.29	0.22	0.02
5	120	0.22	1.05	0.71	0.59	0.31	0.57	0.02
	240	0.21	1.03	0.70	0.52	0.28	0.52	0.02
	360	0.21	1.00	0.70	0.49	0.24	0.49	0.02
6	120	0.12	0.64	0.48	0.45	0.28	0.49	0.01
	240	0.12	0.62	0.39	0.38	0.27	0.46	0.01
	360	0.12	0.62	0.92	0.36	0.25	0.47	0.01
7	120	0.12	0.69	0.50	0.39	0.31	0.45	0.01
	240	0.12	0.67	0.86	0.33	0.31	0.44	0.01
	360	0.12	0.65	0.61	0.29	0.32	0.43	0.01
8	120	0.06	0.14	0.02	0.07	0.13	0.05	0.01
	240	0.06	0.14	0.02	0.07	0.13	0.05	0.01
	360	0.06	0.14	0.02	0.07	0.13	0.05	0.01

RESULTS

For each subject, water temperature, and clothing configuration, predicted Tre was computed and a predicted time to fatality was determined. According to THTM, fatality time represents the point at which the body is unable to generate sufficient internal metabolic heat for survival. Common sense dictates that aircrew be extracted from the water prior to time of fatality; thus a survival time limit was calculated subtracting 20 min from the time of predicted fatality (Table 4). Therefore, as a guide for rescue, the values presented in Table 4 represent the estimated *survival* time limit by which immersed male aircrew should be extracted from the water.

As expected, results from an ANOVA study indicated there was a significant effect of body fat content, water temperature and clothing insulation on survival time. Thus, the predicted ability of stouter individuals to survive long periods of water immersion is higher than for leaner individuals wearing more insulative garments.

Note that the clo values for the head were widely variable even though the same helmet was worn for each run. NCTRF observed that the lower (close to zero) clo values for the head were consistent with water washing over the bare head. Thus, they hypothesized that the waves for some runs could have been higher or rougher than in others, forcing water up under the helmet.

To determine the consequences of this variation, a range of head insulation values were modeled and compared the total time to fatality for the different body types and configurations. It was found that there was a difference, albeit small, on the total time to fatality; stouter individuals were less affected by low head insulation compared to lean individuals. However, since it was not known what the "real" wave effect on head insulation value should be and it was not feasible to repeat or add trials, it was decided to present the data as they are, representing the uncontrollable nature of open-water turbulence.

Table 3: Clothing configurations

	USN TACAIR		USN HELO/PATROL				USAF		USN NONSPECIFIC
	1	2	3	4a	4b	5	6	7	8
CWU-62 Dry Suits									
CWU-86/87 Dry Suits			●	●	●	●	●	●	
OTS-600 Dry Suit	●	●							
CWU-72, 81, and 82/P Liners									
CWU-23/P Liner								●	
MCP Heavyweight Liner			●	●		●			
Xcel Icon Shorty Wetsuit									●
Thermal Insulating Garment							●		
CWU-43, 44/P underwear		●						●	
MCP Lightweight underwear				●	●				
MCP Mid-weight underwear						●			
Standard Wool Socks	●	●	●	●	●	●	●	●	●
CWU-27/P Flight Suit	●	●							●
HGU-84 or 68/P Helmet	●	●	●	●	●	●	●	●	
PCU-56/P Torso Harness	●	●							
CSU-13B/P Anti-G Suit	●	●							
CMU-33 Series Survival Vest	●	●							
Aircrew Safety Boots	●	●							
45º flotation angle							●	●	
90º flotation angle	●	●	●	●	●	●			

USING TABLE 4 TO MAKE OPERATIONAL DECISIONS

Aircrew who are scheduled for flights over cold water can use Table 4 to select the garments they will need to wear using the following steps.

1. Consult with their command to determine likely rescue time given visible light, weather conditions, mission range and duration, and availability of search and rescue assets.
2. Determine the water temperature over which he/she will be flying.
3. Choose the body type in the table that most closely resembles themselves, using body fat as the primary variable, and erring on the lean side.
4. Determine survivability time by matching the water temperature row with the garment configuration chosen. Note that ambient air temperature is not a variable in immersed survival time, because water is much more conductive than air.

Example:

A 135lb. 27% BF female is scheduled for an unescorted night flight that will depart Norfolk, VA and terminate approximately three hours later on an aircraft carrier in the Atlantic. The coldest water temperature over which the crew will fly is 53ºF. The ambient air temperature is 38ºF. Her command estimates that arrival of rescue aircraft from the ship or shore could take at

most 2 hours from time of alert. Experience has taught the crew that, at night, it can take up to an hour to locate someone even if the location is known within yards. She also knows that it takes the rescue swimmer at least 15 minutes to lower, hook-up and complete the hoist. Therefore, she decides to be prepared for 195 minutes survival time.

Since body insulation is more important for survival than mass[6,7], she uses the data provided for the male with 21.2% body fat. She selects the 50ºF water temperature row, but since there is no 195 minute column in the table, she chooses to dress for 235 minutes as the safe bet, and dresses in configuration #4b, the CWU-86/P dry suit worn over lightweight MCP underwear. She does not worry that she is "over-dressing" for the mission conditions, because the model does not predict for females who are known to lose more body heat than men[3], and also does not account for wave effects, fatigue, last mealtime, injuries, attitude, etc., which also compromise survivability.

Table 4. Predicted immersed survival time (min) for nine clothing configurations (described in Table 3), listed from least (#8) to most (#5) insulation provided.

	Configuration:	*8*	*1*	*4b*	*3*	*4a*	*2*	*7*	*6*	*5*
Weight / Body Fat	Water Temp ºF									
140 lb	35	20	60	80	130	145	160	160	160	250
16.8%	40	30	70	100	175	190	190	205	205	310
	45	40	100	130	220	235	250	280	280	360
	50	60	130	175	310	325	310	340	360	360
	55	80	190	250	325	360	340	360	360	360
	60	130	265	360	360	360	360	360	360	360
	68	295	360	360	360	360	360	360	360	360
175 lb	35	30	70	90	145	160	160	175	175	250
19.2%	40	40	90	115	175	190	205	220	220	310
	45	60	100	145	235	250	235	280	295	360
	50	80	145	205	325	325	280	360	360	360
	55	100	205	280	360	360	340	360	360	360
	60	160	310	360	360	360	360	360	360	360
	68	340	360	360	360	360	360	360	360	360
205 lb	35	40	80	100	160	160	175	190	190	265
21.2%	40	60	100	130	190	205	220	235	235	340
	45	70	130	175	250	265	265	310	310	360
	50	100	175	235	340	340	340	360	360	360
	55	130	250	325	360	360	360	360	360	360
	60	205	340	360	360	360	360	360	360	360
	68	360	360	360	360	360	360	360	360	360

WET SUIT VS DRY SUIT FOR "WARMER" WATER TEMPERATURES

In contrast to the fictional decision made above, aircrew often try to wear the bare minimum possible to reduce the distraction due to heat stress. Many feel that a dry suit, even worn with no long underwear, is just too hot for missions over cold water in warm weather. Previous, extensive research has long established superiority of dry suits over full wetsuits to keep wearers

sufficiently warm in water temperatures of less than 55ºF[1,4,8,9]. Nearly as much research has shown that shorty type wetsuits are effective in "warmer" water temperatures (65 to 80ºF).

In order to determine if a short, thin wetsuit could fill the gap between no immersion protection and full dry suit protection while keeping aircrew comfortable during routine flight duties, configuration 8 ("Icon" shorty wetsuit with flight suit over top) was included. In addition to estimating survival time, predicted time to heat exhaustion was also determined using the USARIEM Heat Stress Decision Aid Model (HSDA) version 2.0[11].

A worst-case scenario was chosen that represented a hardworking jet pilot or helicopter aircrew flying in warm weather yet over cold water. The specifications included a 200 W work rate, warm ambient air temperature (70ºF/50% R.H.), full solar load (*e.g.*, glass canopy or aircraft door open), and no evaporative cooling (no aircraft air conditioning or 0 knots wind speed). According to the HSDA model, a full 300 min mission without rest periods or relief from the environment would be achievable for the standard human in the model (154 lb., 67.7 inch male). HSDA does not account for females nor body size/composition. Table 4 indicates that a 295 min survival is probable in above 60ºF water temperatures for each body type. Thus it appears that a thin shorty wetsuit is a feasible compromise for both coldwater immersion protection without excess heat stress during 295 min 70ºF air/60ºF water temperature flight missions, assuming a 295 min alert-to-rescue time.

RECOMMENDATIONS FOR FUTURE RESEARCH

- Develop a validated version of THTM and HSDA to estimate thermal responses for women.
- Conduct a HSDA heat stress simulation for the remaining eight garments. These heat stress data combined with the immersion survivability estimates can be used to generate a family of curves to provide comprehensive mission planning guidance.

ACKNOWLEDGMENTS

The authors would like to thank Mr. Joseph Giblo of the Naval Clothing and Textile Research Facility, Natick, MA who conducted the thermal manikin trials and the USARIEM Heat Stress Decision Aid Model study in November 2004.

REFERENCES

1. Brooks CJ. Ship/rig personnel abandonment and helicopter crew/passenger immersion suits: The requirements in the north Atlantic. Aviat Space Environ Med 1986; 57:276-82.
2. Brooks GA, Fahey TD. Exercise Physiology. Human Bioenergetics and its Applications. New York: Macmillan Publishing Co., 1985.
3. Burse RL. Sex differences in human thermoregulatory response to heat and cold stress. Human Factors, 1979; 21:687-99.
4. Goldman RF, Breckenridge JR, Reeves E, Beckman EL. "Wet" versus "Dry" suit approaches to water immersion protective clothing. Aerospace Med 1966; 37:485-7.
5. Norman R.S. Hollies and Ralph F Goldman (eds). Clothing Comfort: Interaction of Thermal, Ventilation, Construction and Assessment Factors. Ann Arbor Science Publishers, Ann Arbor MI. 1977, pp 7-8.
6. Nunneley SA, Wissler, EH, Allan JR. Immersion cooling: Effect of clothing and skinfold thickness. Aviat Space Environ Med 1985; 56:1177-82.
7. Shender, BS, Kaufman JW. Validation and sensitivity analysis of Texas human thermal model predictions during cold water immersion. Technical Report No. NAWCADWAR-93069-60, Warminster, PA: Naval Air Warfare Center, Aircraft Division, Warminster, 1993.
8. Steinman AM, Nemiroffm MJ, Hayward JS, Kubilis PS. A comparison of the protection against immersion hypothermia provided by Coast Guard anti-exposure clothing in calm vs.

rough seas. U.S. Coast Guard Report No CG-D-17-85. Nat Tech Info Serv. Springfield, VA; 1985 (NTIS #AD-A158413).
9. Steinman AM, Kubilis PS. Survival at sea: The effects of protective clothing and survivor location on core and skin temperatures. U.S. Coast Guard Report No CG-D-26-86. Nat Tech Info Serv. Springfield, VA; 1986 (NTIS #AD-A175316).
10. Wissler EH. Mathematical simulation of human thermal behavior using whole-body models. In: Heat Transfer in Medicine and Biology, Vol. 1, eds: A Shitzer and RC Eberhart. New York:Plenum Press, 1985:325-373.
11. Department of the Army. USARIEM Heat Strain Model, P2NBC2 Heat Strain Decision Aid Implementation, Version 2.1, Army Medical Research and Materiel Command, USARIEM, Natick, MA.
12. Department of the Navy. Naval Air Training and Operating Procedures Standardization General Flight and Operating Instructions. OPNAVINST 3710.7T, 01 March 2004. Chief of Naval Operations, Washington, DC.

BIOGRAPHIES

Barry S. Shender, Ph.D. has worked for the NAVAIR Human Systems Department (4.6) since 1987 at Warminster and Patuxent River. He is currently holds the position of NAVAIR Human Systems Senior Scientist and is a NAVAIR Fellow. Dr. Shender is a Fellow of the Aerospace Medical Association (AsMA) and the Chair of AsMA Science and Technology Committee. He led the team that received the 2003 SAFE Association Award for Team Achievement for the Aircrew Integrated Life Support System program. His technical accomplishments have focused on life support in aviation systems, specifically in determining the relationship between physiologic and cognitive and motor responses to exposures to environmental stresses and the prevention of spinal injury during maneuvering flight, ejection and crash. He is the program manager of two ONR Future Naval Capabilities Warfighter Protection programs in the areas of Injury Prevention and Aircrew Integrated Life Support Systems. Both programs include joint service participation through Defense Technology Objectives and Joint Warfighter Capability Objectives. He has over 68 publications in the crew protection, physiology, and human performance.

Wendy Todd has been a military clothing developer for thirteen years, the last nine of these at the Naval Air Warfare Center. She earned a Master of Science in Clothing and Textiles from Virginia Tech in 1991.